AirMSPI Data Quality Statement
3 December 2013

This statement applies to AirMSPI Level 1B2 Products (Ellipsoid and Terrain) with a version number of 003.

Radiometric Calibration

Laboratory radiometric calibration of the AirMSPI instrument was conducted in September 2011 by observing the output port of a 1.65 m integrating sphere. The sphere illuminates the entire field of view of the instrument. Data were collected at multiple light levels and the sphere output was monitored with an Analytical Spectral Devices (ASD) spectrometer in order to generate a DN vs. radiance regression for each pixel. The AirMSPI line arrays have 1536 pixels in each channel. Offset levels are determined from observations in 100 pixels at the end of each array that are shielded from illumination, hence only 1436 pixels in each line collect image data. The 13 channels of the instrument measure intensity I at wavelengths close to 355, 380, 445, 555, 660, 865, and 935 nm (7 channels); I and Stokes parameter Q at 470, 660, and 865 nm (3 channels); and I and Stokes parameter U at 470, 660, and 865 nm (3 channels). These data are used to generate the intensity and polarization data reported in the 8 spectral bands of the L1B2 product. Linear gain factors on a per-pixel basis for each channel were derived from the integrating sphere observations and applied to the data. Due to the low light output of the sphere in the ultraviolet, and uncertainty the pedigree of the ASD calibration, the resulting gain factors were considered to be a first approximation to the absolute radiometric calibration of the AirMSPI instrument.

In July 2012 AirMSPI underflew the Multiangle Imaging SpectroRadiometer (MISR) instrument aboard the Terra satellite. A patch of clear ocean off the coast of California was observed by both instruments with a time separation of less than 30 minutes. The MISR radiances and aerosol model retrieved by the operational MISR algorithm were used to provide a vicarious calibration of AirMSPI, as described in Diner et al. (2013). This underflight resulted in an adjustment to the gain factors in all channels except the 935 nm intensity band, and these adjusted gain factors were used to process the publicly available AirMSPI products. The 935 nm band was not adjusted because this is a water vapor absorption channel, and modeling the top-of-atmosphere radiances would require ancillary information on the atmospheric water vapor content not available from the MISR instrument itself. Thus, the absolute radiometry for the 935 nm channel is currently more uncertain than for the other bands.

Although gain factors are derived on a per-pixel basis, residual striping can appear in Earth images as a result of imperfect gain determination in certain pixels in the line array. An algorithm to identify such pixels and correct for the residual striping in the pushbroom imagery was developed, making use of in-flight data acquired on January 14-22, 2013. The algorithm works by averaging a large number of lines of data, with each line weighted by a measure of the uniformity of the signal across the field of view. The intent of this step is to average out scene variability. To account for actual variation in

Earth signal across the field of view due to Earth bidirectional reflectance effects, the resulting data were fitted to a low order polynomial. The residuals to this fit provided destriping correction factors. The destriping correction factors derived from this algorithm were applied to the AirMSPI flight data to generate the publicly available L1B2 products.

Radiometric Data Quality Indicators

Following MISR practice, each pixel is assigned a Radiometric Data Quality Indicator (RDQI). The RDQI definitions are as follows:

RDQI = 0: No radiometric issues are identified.

RDQI = 1: The radiometric quality does not meet an identified threshold but is deemed usable for scientific analysis purposes.

RDQI = 2: The radiometric quality does not meet a secondary threshold and the data from this pixel should not be used scientific analysis purposes.

RDQI = 3: The quality of the pixel is scientifically and cosmetically unusable. In addition, the shielded pixels at the end of each line array are marked with RDQI of 3.

All pixels in channels other than 935 nm are given a nominal RDQI of 0. Pixels for which the striping adjustment exceeded 10% of the nominal gain are marked with RDQI = 1. Pixels for which the striping adjustment exceeded 20% of the nominal gain are marked with RDQI = 2. All pixels in the 935 nm band are given a nominal RDQI of 1, since the absolute radiometry is not guaranteed. However, relative angle-to-angle or pixel-to-pixel results are reliable. Any pixels at 935 nm for which the striping adjustment exceeded 20% of the nominal gain are marked with RDQI = 2.

For the 470 nm band, two channels are used to generate the image data reported in the L1B2 product: a channel measuring *I* and *Q*, and a channel measuring *I* and *U*. The RDQI values reported for the band represent the maximum value between these two channels. For the 660 and 865 nm bands, three channels are used to generate the image data reported in the L1B2 product: a channel measuring *I* only, a channel measuring *I* and *Q*, and a channel measuring *I* and *U*. The RDQI values reported for these bands represent the values in the non-polarimetric *I* channel, and are typically 0. There are 4 pixels in the 865 nm *I,Q* channel and 8 pixels in the 865 nm *I,U* channel that have RDQI = 1. The current RDQI reporting does not reflect this. In future versions of the product, RDQI's will be separately reported for intensity and polarimetric quantities.

Other than the radiometric calibration procedures discussed above, independent calibration verification and traceability to National Institute of Standards and Technology (NIST) standards has not yet been performed. For this initial data release, pixels marked with RDQI = 0 are expected to have an absolute radiometric uncertainty of better than 10%. This uncertainty will be reduced in the future.

The interior of the 1.65 m integrating sphere was recently recoated and the sphere was outfitted with Luxim Light Emitting Plasma lamps to increase UV output. Updates to the radiometric calibration, and validation of the radiometric scale using NIST traceable standards are planned for early 2014.

Spectral Calibration

Determination of the detailed spectral response function of each AirMSPI channel is currently in process. A monochromator is being used for this purpose. The spectral response function is equal to the ratio of the camera response to a silicon diode response to the monochromator output at a given wavelength. The intensity of light from the monochromator is a function of wavelength. Two sources are being used in separate spectral scans of all channels — a Luxim Light Emitting Plasma lamp for ultraviolet-blue and a quartz-halogen lamp for the remaining visible and near-infrared channels. We are in the process of validating that the source intensity, particularly in the UV and blue, is high enough to be representative for scenes of scientific interest.

In general, radiometric response at wavelengths beyond the "in-band" spectral region is estimated at $< 10^{-4}$ of the peak response. In the current product release, spectral bands are characterized by the nominal band center wavelengths, and the solar irradiance values (E_0) reported in the L1B2 product correspond to averages over the nominal full width at half maximum in-band region. The Wehrli (1985) extraterrestrial solar spectrum was used for this purpose.

The monochromator used for spectral calibration produces linearly polarized light, where both the degree and angle of linear polarization are functions of wavelength. For the intensity (nonpolarimetric) channels of AirMSPI, the spectral response functions are not affected by the monochromator polarization. For the polarimetric channels, no correction has been made for polarization of the monochromator output. The error in the out-of-band to in-band response ratio increases with the difference between wavelengths. However, because the out-of-band response is $< 10^{-4}$ of the peak response, this error is expected to have negligible impact on the E_0 values reported in the L1B2 product.

The derived spectral response functions, and refined values of the as-built band center wavelengths, spectral bandwidths, and E_0 values will be updated in future releases of the AirMSPI product.

Polarimetric Calibration

AirMSPI uses a time-varying retardance in the optical path to modulate the orientation of the linearly polarized component of the incoming light, described by the Stokes components Q (excess of horizontally over vertically polarized light) and U (excess of 45º over 135º polarized light) (Diner et al., 2007, 2010; Mahler et al., 2011). As a result, the ratios of these parameters to intensity I, given by $q = Q/I$ and $u = U/I$ are to first order insensitive to the absolute radiometric calibration of a given pixel because both the numerator and denominator are determined from signals acquired by the same detector element. The degree of linear polarization (DOLP) and angle of linear polarization (AOLP) derived from these ratios, equal to $\sqrt{q^2+u^2}$ and $0.5\tan^{-1}(u/q)$, respectively, are likewise insensitive to absolute radiometric calibration, based on similar considerations. To compensate for instrumental polarization aberrations (e.g., mirror diattenuation, imperfect retardance), a set of 10 polarimetric calibration coefficients is established for every pixel (Diner et al., 2010). Results from a ground-based version of the instrument, GroundMSPI (Diner et al., 2012), show DOLP uncertainties, determined as the root-mean-square residual in DOLP as a polarizer is rotated in front of the camera, of ±0.003 or better. Results for AirMSPI, using the rotating polarizer methodology described in Diner et al. (2010), show similar residuals.

Georectification and Co-registration

As a part of the ground data processing, AirMSPI data from all spectral bands and all viewing angles are georectified and co-registered to a common Earth-based map (UTM) projection grid. Distortions that can be associated with this type of pushbroom remote sensing imaging are taken into account by properly defining instantaneous pixel projection rays using ancillary data such as estimates of camera internal viewing geometry and ER-2 navigation data, which provide dynamic measures of the platform altitude and attitude variations. There are two types of AirMSPI georectified data products: 1) terrain projected and 2) ellipsoid projected. Terrain-projected data use a digital elevation model (DEM) for the projection surface so that cloud-free imagery is truly orthorectified with reference to that surface. Ellipsoid-projected data use the Earth reference ellipsoid (i.e., WGS 84) for the projection surface. One purpose of the ellipsoid projection is to provide input to stereoscopic height retrievals for predominantly cloudy imagery. Stereoscopic retrieval software is currently in development.

Factors affecting geospatial accuracy of AirMSPI products include: 1) relative band-to-band co-registration within a single viewing angle, 2) multi-angle co-registration, and 3) absolute georectification. The uncertainty depends on the magnitude of the errors in the supplied ancillary data and errors in the projection surface defined by the DEM. In the case of the PODEX campaign, the USGS-provided National Elevation Dataset (NED) with 10 m horizontal posting and 2.44 m rms error in elevation is used. Errors in the ancillary data defining viewing geometry are handled as static and dynamic pointing errors in order to characterize them using available ground control points (GCPs) in a procedure based on simultaneous bundle adjustment (Jovanovic et al., 2012). For targets where there is an optimum number of GCPs available both static and dynamic pointing errors are recovered simultaneously prior to georectification and co-registration. These data are denoted as having full geometric calibration "directly" applied with expected co-registration and georectification uncertainty of around 15 m rms across all viewing angles and all bands. For other targets, i.e., those without available GCPs (mostly fully ocean or cloudy imagery), an estimate of static pointing errors made on separate flight lines within the same campaign is utilized. These products are denoted as having geometric calibration "indirectly" applied with a current estimate of georectification and co-registration uncertainty of less than one hundred meters. The type of geometric calibration is recorded in the file metadata list under the field name “Geolocation stage”. Analysis and implementation efforts are still in progress with an objective to fully optimize the camera viewing model so that uncertainties of indirectly calibrated data are minimized.

Band-to-band relative co-registration uncertainty within the same viewing angle is well within 10 m, which is the pixel size of the map projection grid in the terrain-projected data. In the case of ellipsoid-projected data there will be some offsets in the relative band-to-band registration due to the parallax cased by the true height of the viewing surface and physical band separation in the focal plane. Additionally, note that slight errors in registration can cause a slight displacement (on the order of a degree or two) of polarimetric features such as the backscatter glory from their expected location.

References

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